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Smart IOT-Based Street Light System for Sustainable Cities

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Abstract
A sustainable smart street lighting system for urban areas that combines IoT technology with renewable energy sources is presented. Street lights with PIR and LDR sensors are controlled automatically by the system using ESP32 microcontrollers based on motion detection and ambient light intensity. Energy efficiency is greatly increased thanks to a hybrid energy system that combines solar panels and Savonius wind turbines. A lead-acid battery stores electricity for use at night, while an MPPT controller maximizes solar energy collecting. In addition to promoting sustainable urban infrastructure, the system guarantees decreased energy usage and operating expenses.
Keywords: *IoT, solar energy, Savonius wind turbine, automated street lighting, renewable energy, and sensors*

1. Introduction
street lighting is a crucial component of infrastructure that guarantees security, safety, and visibility. Because they rely only on grid electricity, conventional street light systems use a lot of energy, require frequent maintenance, and have higher operating expenses. Smart, renewable, and automated lighting solutions are becoming more and more necessary as cities transition to sustainable growth. The "Smart IoT-Based Solar and Savonius Wind–Powered Street Light System for Sustainable Cities" project combines intelligent automation with a variety of renewable energy sources. The setup produces electricity day and night using a Savonius windmill and a solar panel. Even in overcast or low-sun situations, power generation is guaranteed by the combination of solar and wind energy. The energy produced is stored in a battery and effectively controlled by sensors like PIR for motion detection and LDR for ambient light detection. Internet of Things (IoT) features, such as automated street light control, performance tracking, and remote monitoring, are made possible by an ESP32 microcontroller. This improves system reliability and lowers the need for manual intervention. This project intends to provide a highly effective, affordable, and environmentally friendly street lighting solution that promotes the idea of smart and sustainable cities by combining solar energy, wind energy, and IoT. Figure 1 shows Flow Chart of the Process

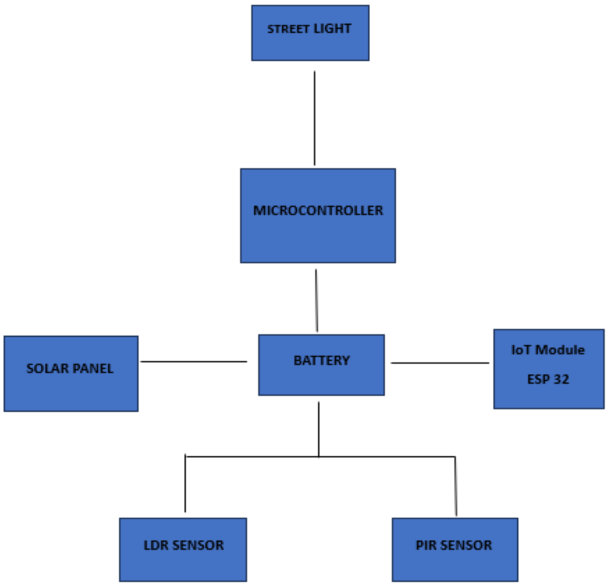

Figure 1 Flow Chart of the Process

During the day, the solar panel absorbs sunlight and transforms it into electrical energy. The battery receives this energy and stores it for use at night. The system operates autonomously without requiring grid electricity thanks to the solar panel.

1.1. Power Storage and Disturbing
All of the system's parts are powered primarily by the

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battery. It supplies steady DC power to:Microcontroller LDR and PIR sensors Light on the street Module for IoT (ESP32).

1.2. Microcontroller operation

The microcontroller serves as the system's central processing unit. Among its primary purposes are: Interpreting sensor data Managing the street illumination Interacting with the IoT component Controlling power use.

1.3.Light Intensity Detection Using LDR Sensor

Light levels in the surroundings are continuously monitored by the LDR (Light Dependent Resistor) sensor. The microprocessor turns off the street light when the LDR detects excessive light levels during the day. LDR detects low light at night, and the microcontroller gets the system ready for lighting.

1.4.Motion Detection Using PIR Sensor

Vehicle or pedestrian movement is detected via the PIR (Passive Infrared) sensor. The street light's brightness is increased by the microcontroller when motion is detected. When there is no motion, the brightness is lowered to conserve energy.

1.5. IoT Monitoring Using ESP32 Module

Real-time data is sent to a mobile app or the cloud by the IoT module (ESP32). It can keep an eye on: Level of battery Status of solar power Status of street lights: ON or OFF Readings from sensors Alerts for faults

2. Results and Discussion

2.1.Performance of Smart IoT Street Lighting

The Convergence Iteration Distribution for four important parameters—velocity, force, torque, and total pressure—is depicted in the pie chart. Velocity has the largest percentage (28.1%) of all of them, meaning that it takes the greatest computing power to stabilize during the simulation. A balanced and consistent convergence behavior is demonstrated by the remaining three parameters, Force, Torque, and Total Pressure, each of which contributes equally at 24%. This distribution shows that velocity plays a more significant and sensitive role, requiring a few more cycles to reach full convergence, even though the system is generally stable across the majority of parameters**.** Figure 2 shows Convergence Iterations for All Goals

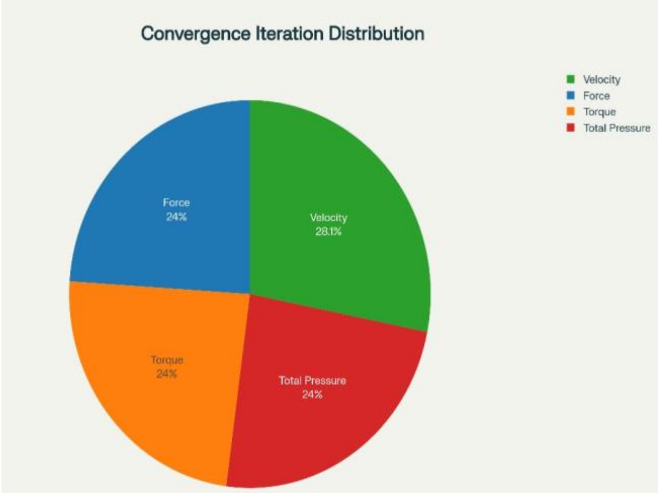

Figure 2 Convergence Iterations for All Goals

2.2.Experimental Input Parameter

The experimental input parameters describe the electrical ratings and functional responsibilities of each component employed in the smart IoT street light system. As the central controller, the ESP32 microcontroller runs at 5 V and determines the light intensity level by reading the PIR and LDR sensors. PIR sensors, likewise provided at 5 V, detect human or vehicle movement, while LDR sensors assess surrounding illumination to discriminate between day, evening, and night circumstances. The LED street lamp is rated at 12 V and provides the principal load, giving bright or dim light according to directions from the controller.

2.3.Convergence Speed (Iterations)

For each of the four simulation objectives—force, torque, total pressure, and velocity—the bar graph displays the convergence speed in terms of iterations. Each of the three parameters—force, torque, and total pressure—converges after 40 rounds, demonstrating consistent and steady computational performance. Velocity, on the other hand, needs 47 iterations, which is significantly more than the others. This implies that, in comparison to the other objectives, velocity takes a little longer to stabilize and is a more sensitive simulation parameter. Overall, the graph shows that velocity requires more iterations for full convergence, but the majority of parameters converge rapidly and reliably. Table 3 shows Components Used in the Smart IoT-Based Solar Street Light System

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Table 3 Components Used in the Smart IoT-Based Solar Street Light System

Component	Description	Role in System
ESP32	Microcontroller with Wi-Fi and Bluetooth	Central controller managing sensor and lights
PIR Senor	Passive Infrared motion sensor	Detects motion to turn lights on/off
LDR Sensor	Light dependent resistor	Measures ambient light to control light intensity
LM7805 Voltage Regulator	Voltage regulator	Provides stable 5V supply to components
Lead Acid Battery	Rechargeable Battery	Stores energy for night-time operation
Solar Panel	Photovoltaic panel	Harvests solar energy to power system
Savonius Wind Turbine	Vertical axis wind turbine	Generates wind energy for hybrid power
MPPT Controller	Maximum Power Point Tracking	Optimizes solar panel energy harvesting
Jumper Wires	Connectors	Connect electrical components
12V DC Motor	Electric motor	Drives actuator or auxiliary functions

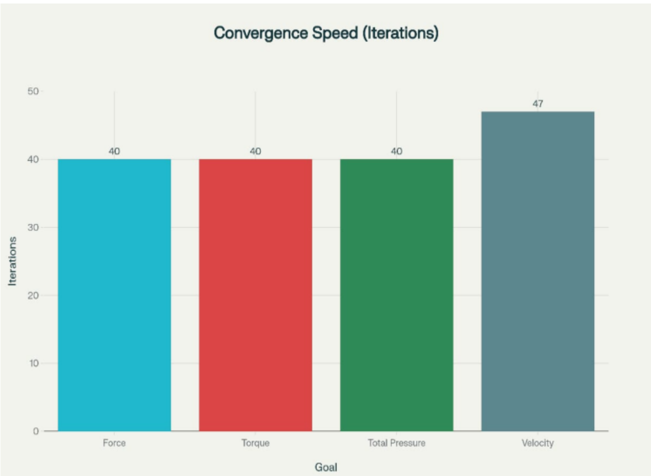

Figure 3 Convergence Speed for Different Goals

2.4.Convergence Behavior of Simulation Parameters

Total Pressure exhibits the most stable behavior among all parameters, remaining almost constant throughout the iterations with very minimal variation, which indicates that it converges early and remains steady. Velocity, on the other hand, increases slowly and steadily from near zero, rising smoothly until it reaches a plateau where it becomes stable, reflecting a gradual but consistent path to convergence. Overall, the plot demonstrates that despite some initial fluctuations, all parameters eventually reach stable values, confirming that the simulation process is well-balanced and reliable. Out of all the parameters, Total Pressure has the most stable behavior, staying nearly constant throughout the iterations with very little change, suggesting that it converges early and stays consistent. In contrast, velocity shows a gradual but steady path to convergence as it rises gradually from almost zero to a plateau where it becomes stable. Overall, the plot shows that all parameters eventually achieve stable levels despite some initial oscillations, indicating that the simulation process is dependable and well-balanced. Figure 3 shows Convergence Speed for Different Goals

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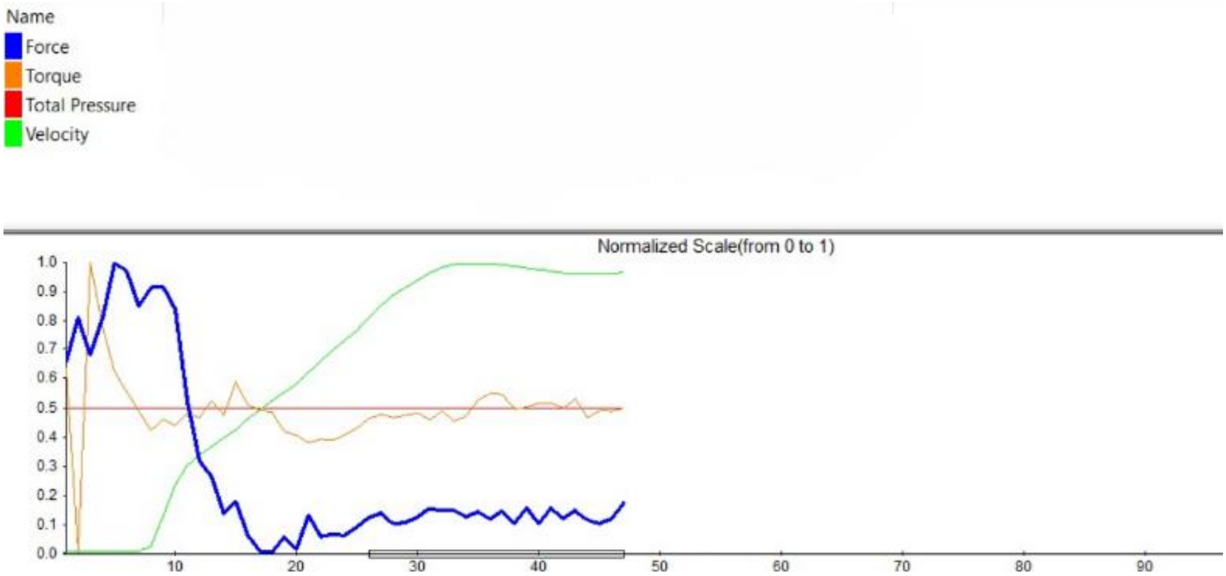

Figure 4 Convergence Trends of Force, Torque, Total Pressure, And Velocity

Conclusion

Automation and renewable energy sources are successfully combined by the intelligent IoT-based street light system to produce effective and eco-friendly urban lighting. The system ensures that lights only turn on when needed by utilizing PIR and LDR sensors with an ESP32 microcontroller, significantly lowering energy loss. When compared to conventional street lights, the integration of solar panels and a Savonius wind turbine offers dependable, clean power and significant energy savings. This strategy is ideal for smart city applications since it not only reduces operating costs but also advances sustainability objectives

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